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VITIATION OF GARAGE AIR BY AUTOMOBILE EXHAUST GASES

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BY

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THE VITIATION OF GARAGE AIR BY AUTOMOBILE EXHAUST GASES.

By G. A. Burrell and A. W. Gauger.

INTRODUCTION.

Among the investigations conducted by the Bureau of Mines there have been several relating to the dangers attending the use of gasoline for fuel and other purposes.[a] Among these dangers is that of the vitiation of the air in inclosed places, such as mines or automobile garages, by the carbon monoxide in the exhaust gases of an internal-combustion engine burning gasoline.

The occurrence of a number of accidents, some of them fatal, whereby people have been overcome through breathing air fouled by the exhaust gases from automobile engines, discloses a hazard that is more serious than it is generally thought to be. Automobile engines frequently run in garages for considerable periods of time, and the exhaust gases unless removed by proper ventilation may make the atmosphere of the garage unsafe. Running an engine in a garage is particularly hazardous in winter when the weather is too cold for keeping doors and windows open.

Death from breathing air vitiated by exhaust gas has in a few instances been termed "petromortis." The cause of death is carbon monoxide poisoning; hence the term petromortis is not a good one for "petro" is from a Greek word meaning "stone." The Travellers' Standard [b] suggests petrol-asphyxia as a better term to indicate the overpowering of persons by fumes originating in petroleum or its products, but this term is not apt, because gasoline vapors themselves cause intoxication and sickness if breathed in sufficient quantity for a long enough time.

EFFECTS OF CARBON MONOXIDE.

Carbon monoxide is a colorless, odorless, and tasteless gas. It is extremely poisonous, because it combines with the red coloring matter of the blood more readily than oxygen does, and blood that

[a] Hood, O. P., and Kudlich, R. H., Gasoline mine motors in relation to safety and health: Bull. 74, Bureau of Mines, 1915, 84 pp. Burrell, G. A., and Boyd, H. T., Inflammability of mixtures of gasoline vapor and air: Tech. Paper 115, Bureau of Mines, 1915, 18 pp. Burrell, G. A., and Boyd, H. T., Quantity of gasoline necessary to produce explosive vapors in sewers: Tech. Paper 117, Bureau of Mines, 1916, 18 pp. Burrell, G. A., Hazards in handling gasoline: Tech. Paper 127, Bureau of Mines, 1915, 12 pp.

[b] Travellers' Standard, May, 1916, p. 92.

is saturated with it can not take up oxygen. Exposure to an atmosphere containing only 0.20 per cent will cause a man at rest to collapse within an hour, and exposure to as little as 0.05 per cent causes headache in several hours' time. Different people are affected differently, and a man at work will be overcome much more rapidly than a man at rest. The dangerous symptoms come almost without warning, and collapse in a garage would prove fatal unless outside aid arrived very soon, because the running engine would continue to generate carbon monoxide and continue to make the air more poisonous. One of the authors of this paper was extremely ill for eight hours after exposure for 20 minutes to air containing 0.25 per cent of carbon monoxide.

RESUSCITATION FROM CARBON MONOXIDE POISONING.

When a person is found overcome in a garage, throw the doors wide open and remove the person to fresh air at once. If a tank of oxygen and a breathing mask are at hand and the person is breathing, administer oxygen through the mask for 20 minutes. If the person is not breathing, give artificial respiration by the prone pressure or Shaefer method. Do not delay. Do not wait for the doctor or for artificial respiration apparatus. Begin at once.

Lay the victim on his belly with his face to one side, so that his nose and mouth are free for breathing. Place one of the victim's arms and hands straight out beyond his head, the other under his head. This position helps to expand his lungs.

Kneel, straddling the victim's thighs and facing his head; rest the palms of your hands on his loins (on the muscles of the small of his back), with your thumbs nearly touching each other and with fingers spread over his lowest ribs.

With arms held straight, swing forward slowly, so that the weight of your body is gradually, but *not violently*, brought to bear upon the victim. This act should take about two seconds.

Then, leaving your hands in place, swing backward slowly, so as to remove the pressure, thus returning for two seconds to the first position.

Repeat deliberately 16 to 20 times a minute the swinging backward and forward—a complete respiration in about four seconds. Keep the movements in time with your own breathing.

While the artificial respiration is being continued, have an assistant draw forward the victim's tongue, if it has fallen back (fortunately it usually falls forward when the victim is face down). Hold the tongue out, if it tends to draw back, by wrapping a handkerchief around it. The handkerchief may also protect the assistant's fingers from being bitten. The assistant should also loosen any tight clothing around the victim's neck, chest, or waist.

Do not permit bystanders to crowd about and shut off fresh air. Keep the victim warm with proper coverings and by placing beside his body hot bricks, bottles, or rubber bags filled with warm (not hot) water. Wrap bricks, bottles, or bags so as to prevent burning the victim.

Continue the artificial respiration *without interruption* until natural breathing is restored, or for at least three hours. If natural breathing stops after being restored, use artificial respiration again.

Do not give any liquid by mouth until the victim is fully conscious. Keep the victim flat. If after being partly resuscitated he must be moved, carry him on a stretcher. It is dangerous to make an ill person sit up or stand. To make him walk may cause death.

PROPERTIES AND PRODUCTS OF COMBUSTION OF GASOLINE.

Gasoline is a mixture of light liquid hydrocarbons of the paraffin series. For it to ignite and explode in an engine cylinder it must first be vaporized and mixed with a certain volume of air. At ordinary temperatures the mixture must contain not less than 1.5 per cent nor more than 5.2 per cent by volume of gasoline vapor in order to be explosive. When the initial temperature is increased the low limit is lowered somewhat until at 400° C. it is 1.1 per cent. Hence a mixture containing less than 1.5 per cent is explosive in a gas-engine cylinder because of the high temperatures therein caused by the initial compression and the incomplete cooling.

The following table gives the results obtained by Burrell and Boyd [a] in their experiments on the products of combustion of gasoline vapor and air mixtures.

TABLE 1.—*Results of experiments to determine products of combustion of mixtures of gasoline vapor and air.*

Percentage of gasoline vapor prior to explosion.	Products of combustion.						
	CO_2.	C_nH_{2n}.	O_2.	CO.	H_2.	Other combustible gas—chiefly CH_4.	N_2.
5.0	2.8	1.3	9.0	8.4	5.8	.....	.....
4.1	5.2	.0	3.4	14.0	10.3	.....	.....
3.6	7.0	.0	1.7	11.6	6.8	.....	.....
3.0	11.4	.0	1.4	4.1	.5	0.1	82.5
2.7	12.1	.0	.6	2.5	.1	.1	84.6
2.6	12.9	.0	.5	1.8	.3	.1	84.4
2.5	13.8	.0	2.8	.0	.0	.1	83.3
2.4	13.0	.0	2.4	.0	.0	.0	84.6
2.1	12.0	.0	3.9	.0	.0	.0	84.1

In some tests with 13 passenger cars and three trucks, Chase [b] showed that the percentages of carbon monoxide formed was at or

[a] Burrell, G. A., and Boyd, H. T., Inflammability of mixtures of gasoline vapor and air: Tech. Paper 115, Bureau of Mines, 1915, 16 pp.

[b] Chase, Herbert, Exhaust gas analysis for economy: Automobile, vol. 30, 1914, pp. 395–442.

near its maximum when the car was running without load. Thus the worst conditions prevail at just the time when they are least desirable. An instructive table prepared by Hood and Kudlich [a] shows the maximum amounts of carbon monoxide that different sizes of engines produce under conditions of proper and improper carburetor adjustment. These results are given in the following table:

TABLE 2.—*Maximum amounts of carbon monoxide that different sizes of engines produce under conditions of proper and improper carburetor adjustment.*

Size of engine cylinder, inches.	Number of cylinders.	Speed, r.p.m.	Piston displacement (cu. ft. per minute)[a].	Maximum probable quantity of noxious gases (cu. ft. per minute at 60° F. with barometer at 30 in.) produced with—				Quantity of air (cu. ft. per minute) required to dilute exhaust gases to 1 part carbon monoxide per 1,000 parts of air.[b]	
				Good carburation.		Poor carburation.			
				CO.	CO_2.	CO.	CO_2	Good carburation.	Poor carburation.
4.75 by 5.25	4	800	172	2.61	6.80	9.91	3.65	2,610	9,910
5 by 5	4	600	136	2.06	5.37	7.84	2.88	2,060	7,840
5 by 5	4	800	182	2.76	7.18	10.48	3.86	2,760	10,480
5 by 6	4	800	218	3.30	8.60	12.56	4.62	3,300	12,560
5.5 by 5	4	600	165	2.50	6.51	9.50	3.50	2,500	9,500
6 by 6	4	700	275	4.17	10.86	15.85	5.82	4,170	15,850
6 by 7	4	500	229	3.47	9.04	13.19	4.85	3,470	13,190
6.5 by 7	4	500	269	4.07	10.63	15.50	5.70	4,070	15,500
6.5 by 8	4	650	299	6.04	15.76	23.00	8.46	6,040	23,000
7 by 7	4	500	312	4.73	12.33	17.97	6.62	4,730	17,970
7 by 7	6	500	468	7.08	18.49	26.97	9.92	7,080	26,970
8 by 7	4	500	407	6.16	16.08	23.45	8.62	6,160	23,450
8 by 7	6	500	610	9.24	24.10	35.14	12.93	9,240	35,140

[a] Area of piston in square feet times length of stroke in feet times number of cylinders times number of revolutions per minute.

[b] Proportion of carbon monoxide permissible in mine air for short and infrequent intervals and not to be exceeded.

EXPERIMENTS.

Experiments were made by one of the authors to determine to what degree the air of a closed garage is vitiated by running an automobile engine. The garage used was 18 feet wide and 24 feet long, with an average height of 11 feet 10 inches. There were two windows, each measuring 1 foot 9 inches by 3 feet 6 inches, and two double doors, each 7 feet 10 inches wide. During the test the doors and windows were kept closed. The automobile was a ¾-ton combination truck with a 4-cylinder 30-horsepower engine. The bore of the cylinders was 3¾ inches and the stroke 5⅛ inches. Most of the samples were taken in vacuum bottles and were analyzed according to the method of Burrell and Seibert.[b] The results are given in Table 3.

[a] Hood, O. P., and Kudlich, R. H., Gasoline mine locomotives in relation to safety and health, with a chapter on analyzing exhaust gases, by G. A. Burrell: Bull. 74, Bureau of Mines, 1915, p. 7.

[b] Burrell, G. A., and Seibert, F. M., The sampling and examination of mine gas and natural gas: Bull. 42, Bureau of Mines, 1913, p. 26.

TABLE 3.—*Analysis of garage air vitiated by exhaust gases from automobile engine.*

Test No.	Sample No.	Location.	Minutes engine running.	Position of—		Analysis.				
				Spark.	Throttle.	CO_2.	CO.	CH_4.	O_2.	N_2.
[a] 1	8	A	4			0.14	0.00	0.00	20.93	78.93
[a] 2	1	Muffler	15			.15	.50	.05	20.65	78.75
[a] 3	7	C	17			.21	.18	.10	20.41	79.10
4	9	A	25	Advanced ⅓	Advanced ¼	.10	.31	.08	20.41	79.10
5	10	C	27	do	do	.15	.64	.05	20.39	78.77
6	11	Muffler	30	do	do	.19	.75	.02	19.89	79.15
7	12	do	32	do	do	.21	1.95	.02	19.13	78.69
[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]	[b]
8	13	C	[c]			.02	.00	.00	20.92	79.06
9	14	Muffler	2	Retarded to limit.	Retarded to limit.	.33	3.00	1.14	17.59	79.94
10	15	do	5	Advanced ½	Advanced ⅛	.38	2.00	.71	18.56	78.35
11	16	do	7	do	do	.53	1.45	.37	19.37	78.28
12	17	do	10	Advanced ⅛	Advanced ⅓	.77	1.98	.94	18.07	78.24
13	18	B	15	do	do	.10	.44	.03	20.59	78.84
[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]	[d]
14	20	A	[c]			.05	.00	.00	20.90	79.05
15	19	Muffler	10	Advanced ½	Advanced ½	.88	1.17	.82	18.73	79.40
16	22	do	20	Retarded	Advanced	.39	.75	.52	19.53	78.81
17	2	A	30	do	do	.23	.20	.05	20.65	78.87
18	3	B, 1 foot from floor.	32	do	do	.24	.53	.03	21.41	78.79
19	4	B, 6 feet from floor.	32	do	do	.20	.49	.00	20.63	78.86
20	5	C	34	do	do	.25	.63	.02	20.34	78.76
21	21	Muffler	35	do	do	.38	3.20	.63	18.35	77.44

[a] Engine running slowly.
[b] Engine stopped and doors and windows opened to ventilate garage. Odor decidedly pungent, much smarting and watering of the eyes of the observer. Garage aired 15 minutes.
[c] Not running.
[d] Engine stopped. Garage aired 15 minutes.

Samples were taken at the muffler, at a place back of the car, represented by B, and at two other places in the garage, represented by A and C.

When gasoline is burned in the presence of enough air, the carbon is almost entirely converted into carbon dioxide and the hydrogen into water. If, however, the amount of air is not enough, besides carbon dioxide and water, carbon monoxide, hydrogen, and methane are formed. As these three gases are all combustible when mixed with air, their presence in the exhaust represents waste. Hence the presence of large amounts of carbon monoxide in the exhaust is to be deprecated as regards both efficiency and safety. Table 1 shows that the carbon dioxide is at its maximum when 2.5 per cent of gasoline vapor is contained in the mixture prior to combustion. From that point the carbon dioxide decreases and the carbon monoxide begins, the latter reaching a maximum at 4.1 per cent of gasoline vapor. The range of complete combustion is very narrow, between 1.5 and 2.5 per cent, so that it is almost impossible to run an engine without producing carbon monoxide at times. Watson [a] has shown that carbon monoxide begins to form with mixtures of 14 parts air by

[a] Watson, W., The petrol engine: Jour. Roy. Soc. Arts, vol. 58, 1910, p. 938.

weight to 1 part of gasoline, and increases to about 12 per cent at 9 parts air to 1 of gasoline. These results are comparable to those of Burrell and Boyd, for Watson's first mixture is approximately 2.5 per cent and the second 3.7 per cent.

DISCUSSION OF RESULTS.

The samples taken at the muffler do not represent the exhaust gas as it comes from the engine, as a sample undiluted by air could not be obtained.

Tests 3, 4, 5, 13, 17, 18, 19, and 20 show to what degree the air in different parts of the garage becomes vitiated with carbon monoxide at various intervals of time. It is interesting to note that at the back of the automobile, at B, there was a slightly higher percentage of carbon monoxide in the sample taken near the floor than in the sample taken 6 feet from the floor. This is not surprising in view of the fact that the exhaust gases are expelled about a foot above the floor. Dangerous amounts of carbon monoxide were present in the farthermost parts of the garage after the engine had run 20 to 30 minutes, whereas near the machine the air was extremely unsafe when the engine had run about 15 minutes.

The observer did not remain in the dangerous atmosphere, except when taking samples or making adjustments, and was not exposed to the poisonous air longer than 30 minutes on the whole. Smarting and watering of the eyes from the presence of other noxious products of combustion was the first effect. After collecting the samples he contracted a headache, and about an hour later became dizzy, nauseated, and ill. This lasted for 10 hours. The next day he was quite well again.

CONCLUSIONS.

Enough carbon monoxide gas may be expelled from the exhaust of automobile engines to render the air of garages poisonous.

In tests made by the authors, garage air was rendered decidedly dangerous after an automobile engine had been running 15 minutes.

An automobile engine should not be run in a small garage unless the doors and windows are wide open.

PUBLICATIONS ON GASOLINE AND ITS UTILIZATION.

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Bulletin 170. Extinguishing and preventing oil and gas fires, by C. P. Bowie. 1918. 50 pp., 19 pls. 4 figs.

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